BROADBAND USW PROCESSING WORKING GROUP

1ST MEETING RESULTS, COMMENTS & RECOMMENDATIONS

Randy K. Young
Leader, Broadband USW Processing Working Group

The Pennsylvania State University
Applied Research Laboratory
PO Box 30
State College, PA 16804
(814) 863-4499 rky1@psu.edu

Nancy Harned
ONR 321US Sponsor

Program Manager: Active USW Processing
800 North Quincy Street
Arlington, VA 22217
(703) 696-4758
harnedn@onrhq.onr.navy.mil

July 18, 1996

Applied Research Laboratory

The Pennsylvania State University

State College, PA

Meeting Minutes from the Broadband USW Processing Working Group

Contents

SUMMARY

On June 12-13, 1996, ONR's Broadband Undersea Warfare Processing Working Group convened its first meeting at The Pennsylvania State University's Applied Research Laboratory. Approximately 30 attendees interacted, discussing the value, status and issues associated with broadband processing for USW. The SYSCOMM, sponsor, laboratory and academic communities were all represented. Discussions ranged from existing operational systems to abstract theory. The attached minutes and results are a product of the entire group and represent the group's initial recommendations.

The focus of the working group was to identify the *potential payoffs of broadband* sensing/processing/modeling, quantify the value-added (or potential value added) by each broadband payoff, determine the status of realizing each payoff, the references associated with its realization, and the issues that must be resolved for practical Fleet utility. The primary documented result of this initial meeting is this list of payoffs and the information associated with each payoff. This list is included as 14 "slides". The intent of these spacious slides is to have reviewers/attendees amend/supplement these slides with their ideas, comments and feedback.

Obviously, other non-documented products of the working group included the interactions between the diverse group members and a new "awareness" between these diverse communities. The stated ONR objectives of the working group (listed in the attached ONR321US presentation) were satisfied. The resulting list of payoffs are in prioritized order (relative to the opinions of our working group only!) and the status of each of these payoffs will help focus future efforts. Due to these successes, the working group will continue to exist and will likely expand its membership and its association with related working groups (a wide consensus of the working group was the requirement to incorporate broadband environmental and sensor information into the broadband processing concepts).

Coordination with related working groups is on-going, attendees continue to interact and provide references and other information, new members have been recommended, and broadband sensing, processing and modeling concepts continue toward Fleet utility. The next Broadband USW Processing Working Group meeting will likely convene prior to the end of 1996 due to the heightened interest and demand for broadband processing. For further information on the Broadband USW Processing Working Group, please contact one of the authors.

ONR 32's Broadband USW Processing Working Group

June 12 & 13 at
The Applied Research Laboratory (PSU/ARL)
The Pennsylvania State University, University Park, PA

Motivations/Deficiencies: Broadband processing is beginning to be more intensely researched by a diverse USW S&T community. Previous broadband processing research efforts were often limited by the immense processing required for its implementation. As computing capabilities have soared and narrowband processing has approached its theoretical limits, broadband processing has become a primary direction for further USW processing gains. By leveraging the basic research in broadband processing common to USW and other diverse applications, a Broadband USW Processing Working Group can efficiently and rapidly educate the USW community and focus/prioritize the broadband processing issues unique to USW. Coordinating these diverse efforts and fusing them with current USW needs and requirements will create a more consistent and rapid understanding of broadband processing concepts, issues, and current status, benefiting the entire USW S&T community.

Approach: The Processing Working Group would hold several technical meetings throughout the year to discuss issues spanning broadband processing: theories, definitions, fundamental processing limitations (environmental/target/sensor effects included), simulations, implementations, etc. These meetings will emphasize the ***generally applicable, abstract broadband processing concepts*** that are common to the diverse applications and concentrate their applicability to USW problems. Culmination of these interactions would result in multiple joint reports and papers.

USW Broadband Processing Working Group Membership (Target initial group size is 20):
ONR, PEO-USW and related Navy sponsors with on-going or proposed broadband processing programs will provide a program representative(s). To reduce the management overhead and maintain focus on the underlying, abstract, common features of broadband ***processing*** (not associated issues), the *initial* membership in the working group will consist of researchers currently under contract to perform broadband ***processing*** research and/or implementation (as well as their Navy sponsors). Additional, "adjunct," members that perform broadband processing outside of the USW application may be consulted and invited to speak to the group as appropriate, such as spread spectrum experts, etc. Obviously, it is intended to grow the membership in this working group in the future. Potentially subgroups will be created for environmental/target/sensor effects (beyond processing).

POC: Nancy Harned, ONR 321US, Program Manager of Active USW Processing....

Applied Research Laboratory
The Pennslyvania State University

ONR's
WIDEBAND USW PROCESSING WORKING GROUP
June 12-13, 1996
ARL's New Building Auditorium

June 12, 1996

8:30	WELCOME & ORIENTATION	Dr. Randy Young
8:45 - 9:15	ARL/PSU OVERVIEW	Dr. Edward G. Liszka
9:15 - 9:30	WORKING GROUP'S CHARGE	Nancy Harned, ONR 321US
9:30 - 12:00 (break included)	BROADBAND DETECTION - 1	Motivation/Payoffs/Ultimate Goals Current Status/References Issues - Specific & Quantified
1:00 - 2:00	BROADBAND DETECTION - 2	Prioritization New Term Goals/Approach
2:00 - 5:00 (break included)	BROADBAND CLASSIFICATION	Motivation/Payoffs/Ultimate Goals Current Status/References Issues - Specific & Quantified Motivation/Payoffs/Ultimate Goals Current Status/References Issues - Specific & Quantified

June 13, 1996

8:30 - 8:45	COMMENTS & FEEDBACK	Nancy Harned, Randy Young
8:45 - 11:30 (break included)	BROADBAND LOCALIZATION	Motivation/Payoffs/Ultimate Goals Current Status/References Issues - Specific & Quantified Motivation/Payoffs/Ultimate Goals Current Status/References Issues - Specific & Quantified
1:00 - 3:00	DISCUSSION, CONCLUSION, FEEDBACK & PLANNING Other issues, such as Environmental & Target Modeling & Characterization	
3:00	CHARGE TO WORKING GROUP	Nancy Harned, ONR 321US

Wideband Processing Working Group Attendees

Last Name	First Name	Registered	Company Name	Work Phone	Fax Number	EmailAddress
Altes	Richard	Yes	CHIRP Corp	(619) 453-4406	(619) 453-4406	
Barton	Bob	Yes	NUWC	(860) 440-5253		barton@vsdec.nl.nuwc.navy.mil
Campbell	Rick	Yes	PEO-USW	(703) 604-6013	(703) 604-6056	campbell-richard@hq.navsea.navy.mil
Chang	Weita	Yes	NUWC	(860) 440-5946	(860) 440-6571	chang@vsdec.nl.nuwc.navy.mil
Dial	Kenneth	Yes	ONR	(703) 696-0806		dialk@onrhq.onr.navy.mil
Harned	Nancy	Yes	ONR	(703) 696-4758		harnedn@onrhq.onr.navy.mil
Hillsley	Ken	Yes	ARL/PSU	(814) 863-4379		klh@sparcy.arl.psu.edu
Jackson	Pam	Yes	NRL/Stennis	(601) 688-4782	(601) 688-5341	pmjackson@nrlssc.navy.mil
Jacobi	Les	Yes	ONR	(703) 696-7021	(703) 696-8423	jacobil@onrhq.onr.navy.mil
Miklovic	Don	Yes	AETC	(619) 450-1211	(619) 450-1794	dmiklovic@aol.com
Novik	Arnie	Yes	PEO-USW	(703) 604-6011	(703) 604-6056	missionsci@aol.com
Pitt	Pat	Yes	ARL:UT	(512) 835-3513		pitt@arlut.utexas.edu
Polcari	John (CDR)	Yes	PEO-USW	(703) 604-6011	(703) 604-6056	
Sands	Scott	Yes	NUWC	(860) 440-6849	(860) 440-6571	sands@vsdec.nl.nuwc.navy.mil
Sibul	Leon	Yes	ARL/PSU	(814) 863-0312		lhs2@psu.edu
Smigel	John	Yes	Lockheed-Martin	(315) 456-1425	(315) 456-1430	johns@spef.syr.ge.com
Smith	George	Yes	NRL/Stennis	(601) 688-5892		george.smith@nrlssc.navy.mil
Symons	Frank	Yes	ARL/PSU	(814) 865-7505	(814) 865-7097	fws2@psu.edu
Tattersall	Matt	Yes	NUWC	(860) 440-5771		tatter@twizzle.nl.nuwc.navy.mil
Titlebaum	Ed	Yes	Univ. of Rochester	(716) 725-4061	(716) 275-2073	tbaum@ee.rochester.edu
Young	Randy	Yes	ARL/PSU	(814) 863-4499		rky@enterprise.arl.psu.edu

BROADBAND SYSTEMS: THE FUTURE OF NAVY ASW OPS

- Operation in harsh littoral environments requires more robust systems
- Smaller, quieter, slower targets are difficult to detect using conventional narrowband processing
- Broadband source technologies are maturing
- Near-future Navy Broadband systems
  - LBVDS
  - EER/IEER
  - LELFAS

BROADBAND PROCESSING WORKING GROUP
OBJECTIVES

- Discuss broadband processing issues for applications to future Navy systems
- Focus & prioritize issues for further research
- Provide opportunity for coordination and cooperation
- Form the foundation for future working group meetings (semi-annual)

BROADBAND PROCESSING WORKING GROUP
ORGANIZATIONS REPRESENTED

- ONR
- PEO-USW (ASTO)
- LBVDS program
- ONR-sponsored 6.2 Active Signal Processing projects
- Other interested signal processing experts

BROADBAND PROCESSING WORKING GROUP

GROUND RULES

- Open forum to facilitate exchange of ideas
- No funding decisions are on the line
- No formal presentations
- Randy Young - moderator (not lecturer)

BROADBAND/WIDEBAND PROCESSING

- What are wideband signals? Wideband processing? Wideband systems?
- Why are they used, needed or even considered?
- Why consider them now?
- What are their payoffs?
- What can we do? What can't we do? Status
- What do we need to do?

WIDEBAND SIGNALS/SYSTEMS

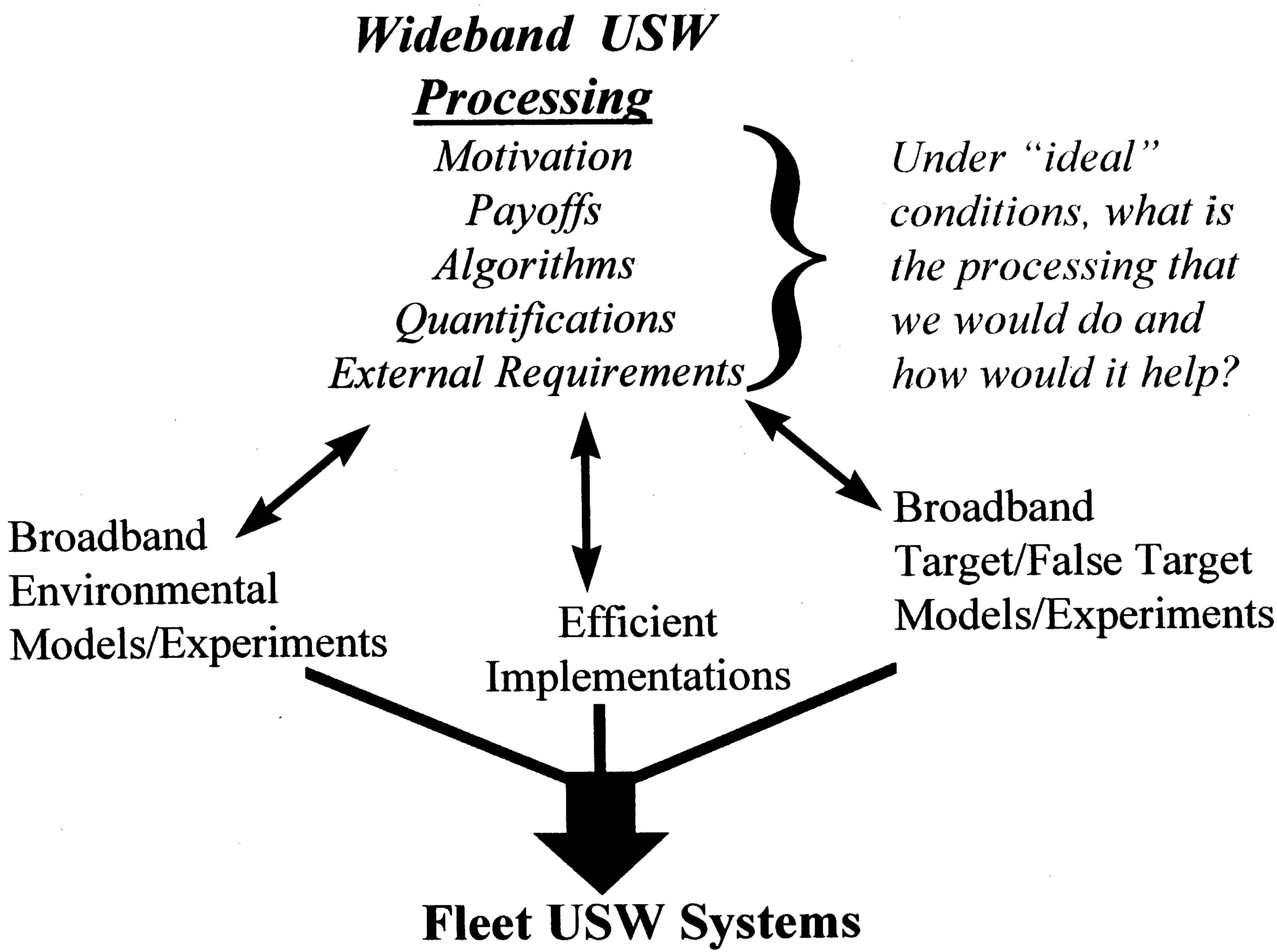
- "Large" bandwidths. Relative to what? center freq, tone,…
- Coherent -vs- noncoherent broadband
- Impulsive -vs- coded signals
- Spread spectrum signals
- Images, speech, noise, …examples

- Time-varying systems - create broadband signals (tone inputs)
- Create new frequencies (nonlinear) - typically more freqs
- Change freq content - time scaling (compression/dilation)

- Processing that operates on broadband signal/systems or models broadband signals/systems are considered "wideband proc."

BROADBAND PROCESSING EXAMPLES

- IMPULSIVE:
  - Ultrasound
    - Biomedical
    - Material imaging
  - Radar (impulse versions)
  - Communications (impulse)
- COHERENT BROADBAND
  - Spread spectrum communications


Wideband USW
Processing
Motivation
Payoffs
Algorithms
Quantifications
External Requirements
Under "ideal" conditions, what is the processing that we would do and how would it help?
Broadband Environmental Models/Experiments
Efficient Implementations
Broadband Target/False Target Models/Experiments
Fleet USW Systems

12 June 1996, New Building Auditorium

Action Items for the Broadband Undersea Processing Working Group

1. Mutual interference, which is associated with broadband processing, is a critical issue that must be examined.

2. Build balanced surface active sonar systems for surface ships. In the next decade, the focus will be on quieting surface ships cheaply by using technologies from the submarine community. LPI (low probability of intercept) is an essential issue.

3. The future of broadband sources lies in the spreading out of the spatial distribution of sources and in multiple sources.

4. Broadband capabilities are still unproven, so more research is needed to define the technical potential.

5. Two approaches support target categorization. The first, which was developed by Dave Nelson in the area of hydrodynamics, establishes a series of point targets. The second focuses on the dispersive effects of submarines through a frequency analysis. In this approach, frequency sweeps and dispersive effects are clearly seen and provide strong evidence.

Performance Quantification

6. Compare our techniques against EER as a baseline.

7. Generate measures of effectiveness.

8. Enunciate the requirements for broadband modeling.

Questions from Commander John Polcari (USN)

1. How do we maximize the 'S' in SNR?
2. How do we minimize the 'N' in SNR?
3. How do we suppress the tails of the 'N' distribution?
4. What's the "right" transmitted waveform?
5. What's the "right" approach to spatial source/receiver diversity?
6. How do we properly address target motion?
7. How do we properly address source/receiver motion?
8. How do we properly address motion of the medium?
9. What approaches for fade/glint resistance?
10. What environmental parameters must be known to "stabilize" the target return?
11. How do we get a handle on these parameters?
12. What multipulse strategies?
13. What strategies can be used to maximize the data rate?
14. What is the "right" approach to spatial aspects of the processing problem, particularly for receivers?
15. In the broadband problem, what is the level of interaction between the spatial aspects and the processing?

Detection — Broadband Enhancement Classification and Localization

Motivation/Goal

1. Low Doppler target
2. Resolution gains – target frequency response/target reconstruction/overresolution/narrower beams
3. Fading resistance – "Brush" filter multipath

Payoffs

Quantified/baseline

1. Reverberation reduction

–Interoperability
–Sparse array (fewer sensors)
–High–rate probing/multi-ping
–Resolution gains for environmental robustness
–Doppler beam sharpening
–Energy gains—time bandwidth
–Covert/LPI active
–Environmental characterization utility of broadband

Approach/Status

–Cite signal processing techniques
–References [Communication theory textbook – Dick Altes needs to provide reference]
[Leon Sibul will provide specific references on using broadband in conjunction with spatial processing]
[Cite reference on optimum 'S' –D. Ricker]
[Don Miklovic can provide references on the nonadaptive beamformer]
[Don Miklovic noted that Lockheed Martin has data sets – who will provide?]
[Don Miklovic will provide SACLANT Center data, and he said a journal article was based on this data set]
[Matt Tattersall mentioned the NUWC data set, but said nothing's ever been done with it]
[Don Miklovic will provide a set of 100 charts]
[LLDS data should be made available]

Issues

1. How do we maximize the 'S' in SNR?

The working group discussed how to optimize 'S'. As explained by Dr. Ricker, one technique is to optimize the receiver, but keep the transmitter the same. By focusing on the receiver's design (where power is the only constraint), the signal is optimized. But Dr. Young noted that many assumptions about optimal situations exist. Commander Polcari asked if a broadband receiver were built, which arrays should be chosen.

At this point of the meeting, our emphasis is shifting to broadband processing payoffs and the issues associated with realizing these payoffs.

General Broadband Processing Issues for Each Payoff

- Medium broadband coherences/losses
- Target response structure
- Processing requirements
- Source coherence
- Target response at all bandwidths
- Theory v. practice
- Coherent v. incoherent broadband noise
- Broadband-"anything" definitions
- Payoff v. cost
- Can you substitute bandwidth for spatial aperture?
- Sufficiency of data
- Mismatch between the assumptions and reality
- Over what regions are these assumptions valid?

Reverberation Reductions (Highest Priority)

Why?	How? (BW ↑)	Quantified NB Comparison	References (Status)	Issues
• Pulse compression (resolution)		• Realize??	• Graduate students under: —Dick Altes —Ed Titlebaum —Leon Sibul —Dennis Ricker	1. Does resolving the reverb. field hurt or help? And when?
• Incoherent — reduced Variance — Diversity	• Environmental Detection		• Broadband 53C —Ed Titlebaum	2. Coherent pulse compression (high time bandwidth) —channel coherence support
• Min $[S^{1**}A_{sig}]$ Reverb —WSSUS —Specular	• Signal design and environmental estimation —Deconvolve			3. Target coherence 4. Source coherence —Array response 5. WSSUS —invalid

Reverberation Reductions (Highest Priority) Cont.

Why?	How? (BW $\uparrow$)	Quantified NB Comparison	References (Status)	Issues
• Spatial Diversity (Broadband)	• Multiple sensors • Spatial correlation • Ambiguity function	?	ARL/UW — Spatial Correlation	

Low-Doppler Target Detection

Why?	How? (BW ↑)	Quantified NB Comparison	References (Status)	Issues
• Reverb reduction • Range / cross-range • Resolution / motion	• SNR gain • (Mis) Matched filtering • Signal design • Biologically (BASS algorithm) • Twin processor • Operator's audio quality		Newhall waveform (grating lobes in Doppler traded off for ϕ-Doppler resolution)	1. Coherence 2. Motion compensation 3. Environmental spreading — multipaths 4. Glint 5. Transmit signals 6. Audio quality — issue unknown

Resolution Gains (Target Reconstruction)

Why?	How? (BW ↑)	Quantified NB Comparison	References (Status)	Issues
• Coherent / noncoherent gains (variance reduction)	• Wavelet estimator-correlator	$S_T(x, x^1)$??	• L. Sibul	1. Characterizing structure —Spatially —Frequency response of highlights
	• Knowing target scattering function			2. Decouple from environmental response
	• Sequential imaging and RAKE			
	• Temporal target highlight classifier (NUSC)		• Scott Sands provided a reference from NUWC	

Resolution Gains (Target Highlight Structure)

Why?	How? (BW ↑)	Quantified NB Comparison	References (Status)	Issues
• Resolution gains	• Twin processors (reduce sidelobes)			1. Medium
• Pulse compression	• SCAT (Spectrogram Correlation and Translations)		• Jim Simmons' article	2. Ping-to-ping consistency
	• BASS			3. Target/medium/ coherence
	• Broadband monopulse		• Terry Anderson's work (funded by ASDO)	4. Nonlinear effects
	• Cepstrum		• D. Ricker	5. SCAT has a problem with ghosts (ref. Jim Simmons)
			• Weiner/Turin (ask Dick Altes)	

Resolution Gains (Target's Frequency Response)

Why?	How? (BW ↑)	Quantified NB Comparison	References (Status)	Issues
• Acoustic color	• Spectral classification		• Don Miklovic	1. Knowing target frequency response v.: —False targets —Environment —CMs
			• Pat Pitt	2. Effect of spatial view (aspect)/ depth
	• Highlight type classification		• ~~Larry Riddle/ Patrick Flawber ref. (given by George Smith)~~	3. Motion effects — target and sensors
	• ~~GABOR~~		• ~~(George Smith will provide ref.)~~	4. Validity of TAP model (ref. Harry Cox of Orincon — given by Don Miklovic)
				5. Search/adapt stationarity and variability

Resolution Gains (Target's Frequency Response) Cont.

Why?	How? (BW ↑)	Quantified NB Comparison	References (Status)	Issues
				6. Validity of the geometric theory of diff~~erence~~raction model (five categories of different test scatters)
				7. Validity of scaled model responses v. full-scale

Reduce Fading and Glint

Why?	How? (BW ↑)	Quantified NB Comparison	References (Status)	Issues
• Reduced constructive / destructive interferences	• BRUSH		• L. Sibul	1. Variability / stationarity robustness in estimating multipaths
	• RAKE		• ref. Dick Altes	
	• Diversity —Spatial —Frequency —Time		• "Noise Propagation in SW" [Ed Titlebaum read]	
			• Dennis Ricker	
	• Waveform design		• Ben Jones of TRACOR (ref. given by Scott Sands of NUWC)	
	• Multipath compensation			

Enhanced ~~Beampatterns~~ space time processing

Why?	How? (BW ↑)	Quantified NB Comparison	References (Status)	Issues
• Grating lobe reduction	• Don— nonuniform arrays • General ambiguity functions Adaptive proc. High resolution	• Time delay v. phase		1. Array design 2. Sensitivities —Spacing, frequency... 3. Position errors 4. Variability 5. Baffle effects 6. Coherent v. incoherent 7. Susceptibility to NB interference

Covert / LPI Operations

Why?	How? (BW ↑)	Quantified NB Comparison	References (Status)	Issues
	• Spread spectrum signals		• Many textbooks describe spread spectrum. (Ed Titlebaum)	1. How good?
	• Agility			2. The signals are still useful. —Spreading/ motion
	• Biological			3. Propagation loss (one-way)

Better Environmental Characterization

Why?	How? (BW ↑)	Quantified NB Comparison	References (Status)	Issues
• Excite more modes	• Probe pulses			1. Utility of same waveforms and processing for environmental characterization and target DCL
• Exploit dispersiveness (exploit channel for pulse compression)	• CDC Program	• Frequency propagation loss —Sustained charges	• Bob Barton	2. Can you substitute bandwidth for spatial aperture?
• Use propagation structure	• Deconvolutions/ twin receiver		• Bruce Williams of NRAD	3. Spanning multiple frequency regions — validity of the models?
• Noncoherent	• UPF		• Steve Wolf (NORELL) [given by George Smith)	4. Sensitivity of deconvolution and other approaches
• Frequency responses —Reverberation —False targets (fish) —Targets	• Mode excitation • Wideband/ wavelet/space-time-varying spreading function	• Modal compression analysis of the target and environmental research	• Scott Sands provided a reference	5. Trying to solve inverse problems 6. Stochastic v. deterministic

Interoperability Gains

Why?	How? (BW $\uparrow$)	Quantified NB Comparison	References (Status)	Issues
• Reduction of sidelobes (Don Miklovic/Dick Altes)	• Multistatics			*All of the general issues apply in a bistatic sense.*
• Reduce mutual interference	• Beampatterns			1. Structure of reverberation
• Sensor reuse	• Coded signals			2. Implementa-tion/cost
• Bistatic motion	• Band overlap			3. Sensor reuse
	• Spatial diversity/ multiple sensors			4. Interference
				5. Operational constraints —Configuration —Signal type

Smaller / Cheaper / Sparse Arrays

Why?	How? (BW ↑)	Quantified NB Comparison	References (Status)	Issues
• Sensor reuse	• Band overlap			1. Efficiencies
•Cost	• Broadband beamforming			2. Theory v. practical
	• Monopulse			3. Transducer v. system level
	• Split aperture		• Henderson [given by Pat Pitt]	4. Reverberation statistics
	• Synthetic aperture			5. Array design/ aperture stability

High-Rate Probing / Sensing

Why?	How? (BW ↑)	Quantified NB Comparison	References (Status)	Issues
• Continuous view	• Multi-ping			1. Self-interference
	• Frequency diversity			2. Stability/ variability
	• Code diversity			3. Motion effects
	• UPF			4. Reverberation
	• Continuous wave FM (CWFM)		• Newhall?	5. Source —Power —Duty cycle
	• Sweeping ambiguity region		• Matt Tattersall gave ref.	

Energy Gains

Why?	How? (BW ↑)	Quantified NB Comparison	References (Status)	Issues
• High time bandwidth		•Time bandwidth		1. Implementation
• Maintain range resolution (more energy)				2. Cavitation

Broadband References

Altes, Richard, "Wideband Acoustic Imaging Results," Presented at the ONR Broadband Processing Working Group, ARL Penn State, University Park, PA, 12–13 June 1996.

Culver, R. L., Ricker, D. W., and Johnson, B. L., "The Characterization of a Waterborne Acoustic Channel Using Matched Filter Deconvolution," *Proc. Environmental Acoustics Specialists Conference on Shallow Water Reverberation*, DRA, Portland, U. K., 23–24 June 1992, (equal co-author, invited paper).

Culver, R. L., Ricker, D. W., Sibul, L. H., and McCammon, D. F., "High Frequency Environmental Requirements for Shallow Water ASW," *Journal of Underwater Acoustics*, Vol. 42, No. 4, pp. 1343–1379, 1992.

Drumheller, D. M., and Ricker, D. W., "Receiver-Transmitter Optimization for Detection in Doubly Spread Channels," *Journal of the Acoustical Society of America*, Vol. 89, No. 4, pp. 1714–1722, 1991, (co-author, supervised student).

Johnson, B. L., Ricker, D. W., and Sacha, J. R., "The Use of Iterative Deconvolution for Scattering Function Identification," *Journal of the Acoustical Society of America*, Vol. 91, No. 5, pp. 2790–2798, 1992, (co-author, supervised student Johnson).

McConnell, Steven O., and DeProspo, Douglas F., "Broad-Band Bottom Forward Loss and Backscattering off San Diego," *IEEE Journal of Oceanic Engineering*, Vol. 19, No. 7, pp. 360–367, July 1994.

Miklovic, D. W., Achieving High Broadband Performance with Narrowband Sonar Arrays, Report No. SD-063-007.1-96-TR, AETC Incorporated, San Diego, CA, May 1996.

Ricker, D. W., and Saridis, G. N., "Analog Methods for On-Line System Identification Using Noisy Measurements," *Simulation V*, Vol. 11, No. 5, pp. 241–248, 1968, (principal author).

————————, "On-Line Identification of a Class of Non-Linear Systems from Noisy Measurements," *Automatica*, Vol. 7, pp. 517–522, 1971, (principal author).

Ricker, D. W., and C. L. Key, "Isolation Techniques for Reducing Torpedo Radiated Noise," *Journal of Underwater Acoustics*, Vol. 25, No. 2, pp. 351–361, 1975, (principal author).

Ricker, D. W., "A Non-Linear Feedback System for the Normalization of Active Sonar Returns," *Journal of the Acoustical Society of America*, Vol. 59, No. 2, pp. 389–396, 1976.

Ricker, D. W., and Skinner, D., "Single Pulse Synthetic Aperture Sonar," *Journal of Underwater Acoustics*, Vol. 30, No. 4, pp. 413–422, 1980, (equal co-author).

Ricker, D. W., "A Logarithmic Frequency Allocation Algorithm for Wideband Discrete Frequency Pulse Trains," *IEEE Trans. Aerosp. and Elect. Systs.*, Vol. 18, No. 3, pp. 347–349, 1982.

——————, "Echo Waveform Synthesis in a Rapidly Varying Geometry," *Journal of the Acoustical Society of America*, Vol. 72, No. 4, pp. 1321–1323, 1982.

——————, "Comments on Doppler-Time Mapping," *Journal of the Acoustical Society of America*, Vol. 73, No. 5, pp. 1864–1865, 1983.

——————, "Receiver Operating Characteristics for Frequency Agile Active Diversity Sonars," *Journal of Underwater Acoustics*, Vol. 35, No. 3, pp. 321–331, 1985.

——————, "Small Aperture Angle Measurement for Active Echo Location Systems," *IEEE Trans. Aerosp. and Elect. Systs.*, AES-22, No. 4, pp. 380–388, 1986.

——————, "Multitone Code Design for Active Diversity Detection," *Journal of Underwater Acoustics*, Vol. 38, No. 4, pp. 401–409, 1988.

——————, "A Non-Iterative Time Mapping Algorithm for Linear Motion in 3-Space," *Journal of the Acoustical Society of America*, Vol. 89, No. 3, pp. 1198–1200.

Ricker, D. W., and Sacha, J. R., "Sonar Detection and Imaging in an Arctic Context," *Journal of Underwater Acoustics*, Vol. 39, No. 4 (pt. II), pp. 1163–73, 1989, (equal co-author).

Ricker, D. W., Sacha, J. R., Drumheller, D. M., Gustafson, M. J., and Cutezo, A. J., "Sonar Imaging and Discrimination in the Range Doppler Plane," *Journal of Underwater Acoustics*, Vol. 40, No. 3, pp. 583–626, 1990, (equal co-author).

Ricker, D. W., "The Doppler Sensitivity of Large TW Phase Modulated Waveforms," *IEEE Trans. on Signal Processing*, Vol. 40, No. 10, pp. 2406–2413, 1992.

————————, "Constrained Bandwidth Waveforms with Minimal Dilation Sensitivity," *IEEE Trans. Aerosp. and Elect. Systs.*, Vol. 29, No. 3, pp. 666–679, 1993.

Ricker, D. W., and Cutezo, A. J., "The Estimation of Coherent Reverberation Processing Gain Using Scattering Functions," *Journal of Underwater Acoustics*, Vol. 43, No. 1, pp. 179–200, 1993.

Ricker, D. W., and Gustafson, M. J., "A Low Sidelobe Technique for the Direct Measurement of Scattering Functions," *IEEE Journ. Oceanic Eng.*, Vol. 21, No. 1, pp. 14–23, 1996.

Ricker, D. W., and Cutezo, A. J., "The Multitone Crosscorrelation Detection of Spread Scattering Processes," *Journal of Underwater Acoustics*, Vol. 44, No. 4, pp. 1085–1112, 1994.

Ricker, D. W., "Vibration Isolation in Underwater Vehicles," *Proc. TTCP Subgroup G Conf. on Self and External Noise*, Invited paper presented at Portland, U.K., 24–29 June 1973.

————————, "Reduction of Radiated Noise," *Proc. 30th Navy Symp.*, Washington, D.C., 24 Oct. 1974.

————————, "Radiated Noise of Underwater Vehicles," *Proc. TTCP Subgroup G Conf. on Radiated Noise*, Teddington, Middlesex, U.K., 22 March 1977.

————————. "Synthetic Aperture and Broadband Signal Processing for Sonar Applications," *Proc. TTCP Conference on High Resolution Processing*, Weymouth-Portland, U.K., 23 Sept. 1982, (invited paper).

———————, "High Resolution Imaging with Wideband Synthetic Aperture Sonar," *Proc. Active Echo Classification Workshop*, New London, Ct., 18–19 Sept. 1984.

———————, "Image Generation and Processing in the Range-Doppler Plane," *Proc. Active Classification Symp.*, New London, Ct., 18–20 Nov. 1987 (invited paper).

Ricker, D. W., and Cutezo, A. J., "Receiver Reverberation Performance Prediction Using Scattering Functions," *Proc. Environmental Acoustics Specialist Conference on Shallow Water Reverberation*, DRA, Portland, U.K., 23–24 June 1992, (principal author, invited paper).

Pitt, Pat, SonoPanel™ Piezocomposite Hydrophone/Actuators, Materials Systems, Inc., Littleton, MA, May 1995.

Sands, Scott, "Classification by Highlight Analysis," *Journal of Underwater Acoustics*, January issue. (Accepted for publication).